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BASIC RESEARCH

Is Crestal Placement of Short Plateau Implants Really Challenging for their Prospect in the Maxilla?

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Abstract

Plateau short implants have become popular in critical cases of edentulous posterior maxilla. For insufficient bone height, the standard protocol of subcrestal placement is inapplicable, so crestal insertion becomes the only option. Unfortunately, it often leads to stresses increase in bone-implant interface, which causes implant failure. Finite element (FE) method provides biomechanical evaluation of bone-implant structures and influence of bone quality and implant parameters on bone stresses.

The aim of the study was to evaluate the impact of crestal placement of particular short plateau implants on stress magnitudes in atrophic posterior maxilla under oblique functional loading to predict bone overload and implant failure.

Nine Bicon Integra-CP™ implants with 5.0 (S), 6.0 (I), 8.0 (L) mm length and 4.5 (N), 5.0 (M), 6.0 (W) mm diameter were selected for this study. Their 3D models were placed in 36 posterior maxilla segment models with types III and IV bone, 1.0 (A) and 0.5 (B) mm crestal cortical bone thickness. These models were designed using CT images in Solidworks 2016 software. Implant and bone were assumed as linearly elastic and isotropic. Elasticity modulus of cortical bone was 13.7 GPa, cancellous bone – 1.37 GPa (type III) and 0.69 GPa (type IV). Bone-implant assemblies were analyzed in FE software Solidworks Simulation. 4-node 3D FEs were generated with a total number of up to 2,518,000. 120.92 N mean maximal oblique load (molar area) was applied to the center of 7.0 mm abutment. Von Mises equivalent stress (MES) distributions in surrounding bone were studied to determine the areas of bone overload with magnitude >100 MPa in cortical and >5 MPa in cancellous bone.

Maximal magnitudes of MESs were found in crestal cortical bone in the plane of critical bone-implant interface. The spectrum of maximal MESs was between 15.2 and 40.5 MPa. The highest MESs were found for all N,IV,B scenarios (34.4-40.5 MPa), while the smallest magnitudes were determined for all W,III,A scenarios (15.2-16.5 MPa). For all tested implants, maximal MES magnitudes were significantly influenced by cortical bone thickness and implant dimensions, yet they were not susceptible to bone quality: for type IV bone scenarios compared to type III, MES increase was within the range of 12-19%. Besides, for 0.5 mm cortical bone thickness scenarios, 18-19% increase was determined and it was not dependent on implant diameter. MESs around N implants were found to be prone to their length decrease, especially for 0.5 mm cortical bone.

The outcomes of this study enhance understanding of the stress characteristics in the maxilla surrounding different-sized short plateau implants. Studied Bicon implants have not caused 100 MPa ultimate stresses in crestal bone under mean, and even 275 N maximum experimental load. This study supports clinical success of plateau implants in posterior maxilla due to their low susceptibility to poor bone quality. It provides a rationale for appropriate implant selection for posterior maxilla.

Background and Aim

Endosseous dental implants have become a predictable treatment option for patients with edentulism[1]. The success rate of dental implants is mainly associated with bone quality and quantity, so higher amount of implant failure occurs in the posterior maxillary region with insufficient bone height and poor bone quality[2]. At the same time, occlusal loads are significantly higher comparing to the frontal area. Other factors that may cause failure and difficulty in implant placement in the posterior maxilla are limited visibility, reduced interarch space, and sinus pneumatization due to post-extraction bone loss[3]. Surgical procedure, such as sinus augmentation, is used to improve bone quantity and allows conventional implant placement[3-6]. However, this procedure is associated with increased postoperative morbidity, higher costs and risks of complications[4-7], e.g. sinus membrane perforation, maxillary sinusitis, etc.[8,9]. But even after sinus lifting, bone quality and quantity is not predictable, and it influences the implant load-carrying capacity.

In posterior maxilla with insufficient bone height, placement of short implants provides a successful alternative[10]. Short implants have been defined as less than 8 mm in intrabone length[11]. Advantages of short implants include avoidance of additional surgery such as augmentation, easier treatment planning, shorter treatment period, reduced chance of complications, lower cost, less bone overheating[12-14]. Moreover, studies have revealed that the failure rate of short implants was not higher than that of long implants[9,15].

Contrarily, short implants have smaller implant surface area leading to reduction of the bone contact area and increased stress and strain concentrations in crestal bone. Nowadays, this issue is overpassed through modification of implant shape and surface treatment[3]. Among various shapes of short implants, Bicon® plateau design is one of the most widely used types[16,17].

In case of insufficient bone height, wide short implants could be used to increase the surface area and to improve stress and strain distributions in the supporting bone[18], in particular, at the implant neck, which is considered the most critical area of the bone-implant interface from the biomechanical perspective[19].

The finite element (FE) method is a contemporary tool to simulate mechanical behavior of complex dental systems under functional loading[20]. Stress fields around bone-implant contact area are affected by implant dimensions and mechanical properties and surrounding bone quality/quantity. Inadequate implant dimensions are the most crucial cause of peri-implant bone overload and further bone/implant loss.

The aim of the study was to evaluate the impact of crestal placement of Bicon Integra-CP™ implants on stress magnitudes in atrophic posterior maxilla under 120.92 N mean maximal functional load[21] to predict bone overload and eventual implant failure.

Methods and Materials

Nine Bicon Integra-CP™ implants with 5.0 (S), 6.0 (I), 8.0 (L) mm length and 4.5 (N), 5.0 (M), 6.0 (W) mm diameter were selected for this study. Posterior maxilla segment 3D models were designed in Solidworks 2016 software using CT images (Fig. 1). Their dimensions were selected to simulate the most critical scenario of minimal available bone to fit the specific implant with crestal placement as a necessary compromise. Bone segments with 1.0 (A) and 0.5 (B) mm crestal cortical bone thickness consisted of types III/IV bone simulated by different cancellous bone elasticity moduli. Implant and bone were assumed as linearly elastic and isotropic and all materials volumes were considered homogeneous. Implant models were placed in jaw segment models with implant apex supported by sinus cortical bone (see Fig. 1). The size of maxilla segment was 30×9×11 mm (length × height × width). Implants and abutments were considered as a continuous unit and were assumed to be made of titanium alloy with the modulus of elasticity and Poisson's ratio of 114 GPa and 0.34, respectively[22].

The Poisson's ratio of bone tissues (both cortical and cancellous) was assumed to be 0.3[23]. Elasticity modulus of cortical bone was 13.7 GPa[23] for both bone quality types, for Type III bone cancellous bone it was 1.37 GPa and for type IV - 0.69 GPa. Ultimate tension strength of cortical and cancellous bone were 100 and 5 MPa[22].

With respect to boundary conditions, disto-mesial surfaces of the bone segment as well as upper cortical shell planes in all models were restrained (see Fig. 1).

Loading of implant was performed at the center of 7.0 mm abutment, in 3D, by 120.9 N mean maximal functional load[21] applied obliquely at the angle of approximately 75° to the abutment top surface. Components of functional loading were determined as 116.3, 17.4 and 23.8 N in axial, lingual and disto-mesial directions. The last two components represent the resultant vector of 29.5 N horizontal functional load acting in the plane of critical bone-implant interface. All implants were assumed to be completely osseointegrated.

Bone-implant assemblies were analyzed in FE software Solidworks Simulation. 4-node 3D FEs were generated with a total number of up to 2,518,000. The example of FE meshing for 4.5 mm diameter implant and A segment is shown on Fig. 2.

For implants success / failure analysis, von Mises equivalent stress (MES) was selected as the measure of bone failure risk. MES distributions in bone peri-implant area of 36 bone-implant assemblies were studied to calculate maximal MES values. Areas of bone overload with MES magnitude greater than 100 MPa in cortical and 5 MPa in cancellous bone were analyzed.

Results

Analysis of MES distribution in cortical bone has showed that their maximal values were found on the outer surface of crestal bone. This statement is supported by MES distributions along the critical bone-implant interface. Illustration of MES distributions for 12 tested bone-implant assemblies is shown on Fig. 3. Corresponding graphs along conical neck generatrix are represented on Fig. 4, 5. The spectrum of maximal MESs was between 15.2 MPa (III,A,W,L) and 43.5 MPa (IV,B,N,S). Maximal MESs were influenced by cortical bone thickness and bone quality. E.g., for 5.0 mm length (S) implants, MES reduction due to cortical bone thickness increase from 0.5 to 1.0 mm was 28.7, 32.5, 12.5% for N, M and W implants and type IV bone, while for type III it was 22.8, 27.1, 10.0%. W implant was found more appropriate than N due to sufficient MES reduction: for 5.0 mm length (S) implants – 35.3% (III,A), 44.4% (III,B), 32.3% (IV,A) and 44.8% (IV,B); for 6.0 mm length (I) implants – 47.3% (III,A), 47.2% (III,B), 46.6% (IV,A) and 47.1% (IV,B); for 8.0 mm length (L) implants – 46.7% (III,A), 48.0% (III,B), 53.9% (IV,A) and 49.2% (IV,B).

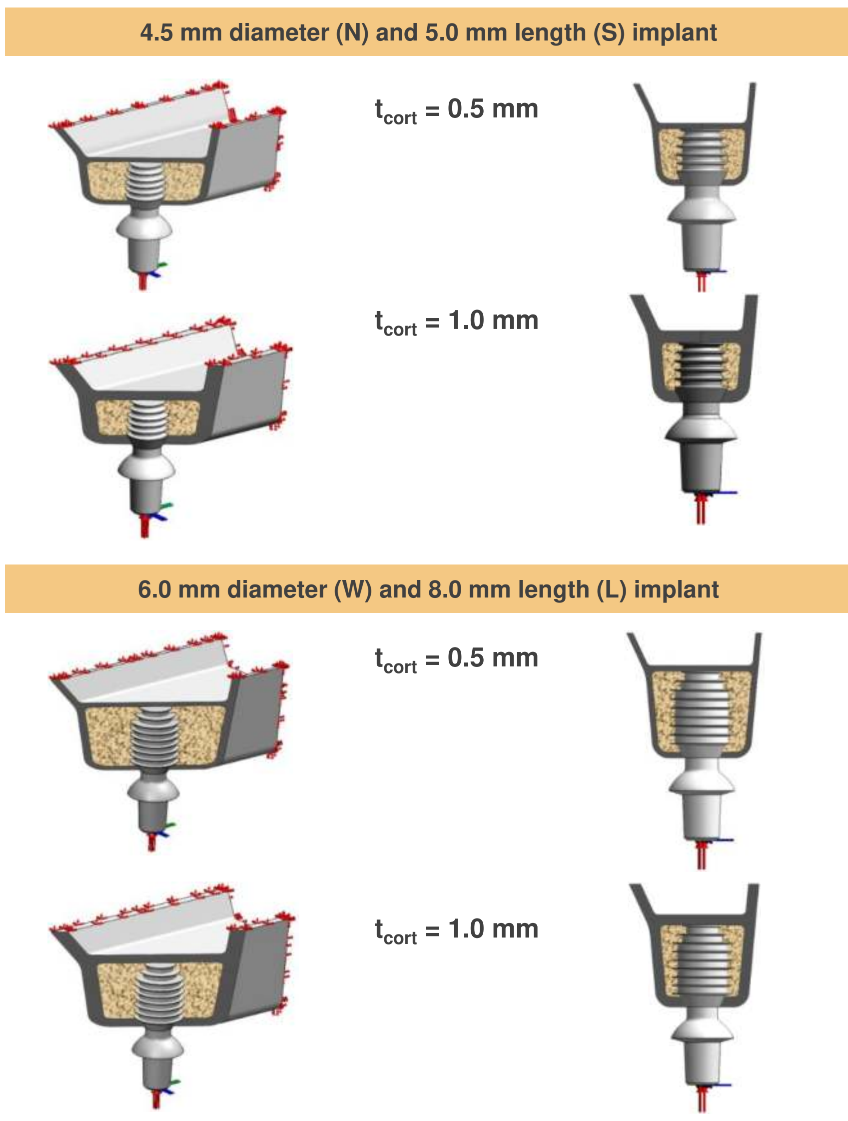


Fig. 1. Maxillary bone segments of 0.5 and 1.0 mm crestal and sinus cortical bone thickness with inserted 4.5×5.0 and 6.0×8.0 mm implants. Oblique loading is applied to the center of abutment upper surface at 7.0 mm distance from the upper bone margin.

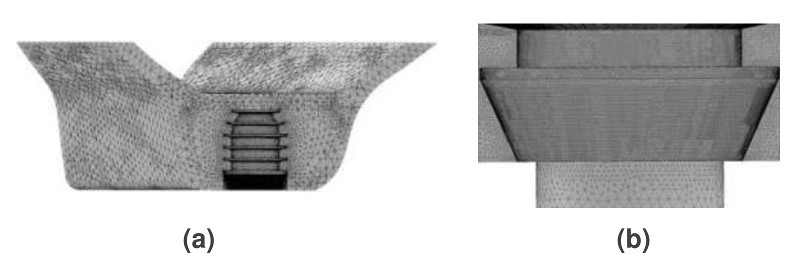
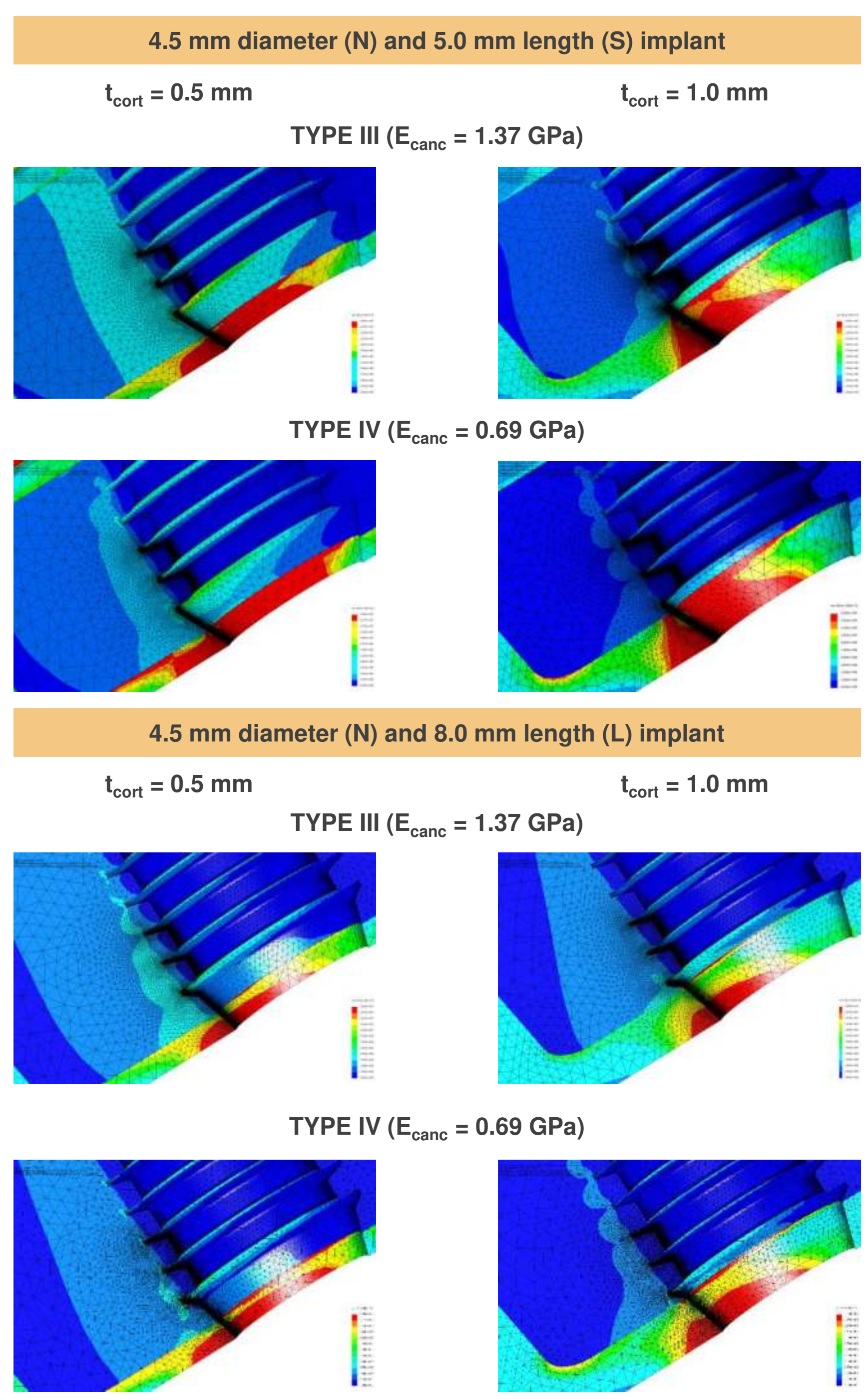


Fig. 2. (a) FE meshing of maxillary bone segment with 1.0 mm crestal and sinus cortical bone and 4.5×5.0 mm implant. (b) Mapped meshing in the neck area of bone-implant contact. Minimal value of FE size is 0.025 mm.



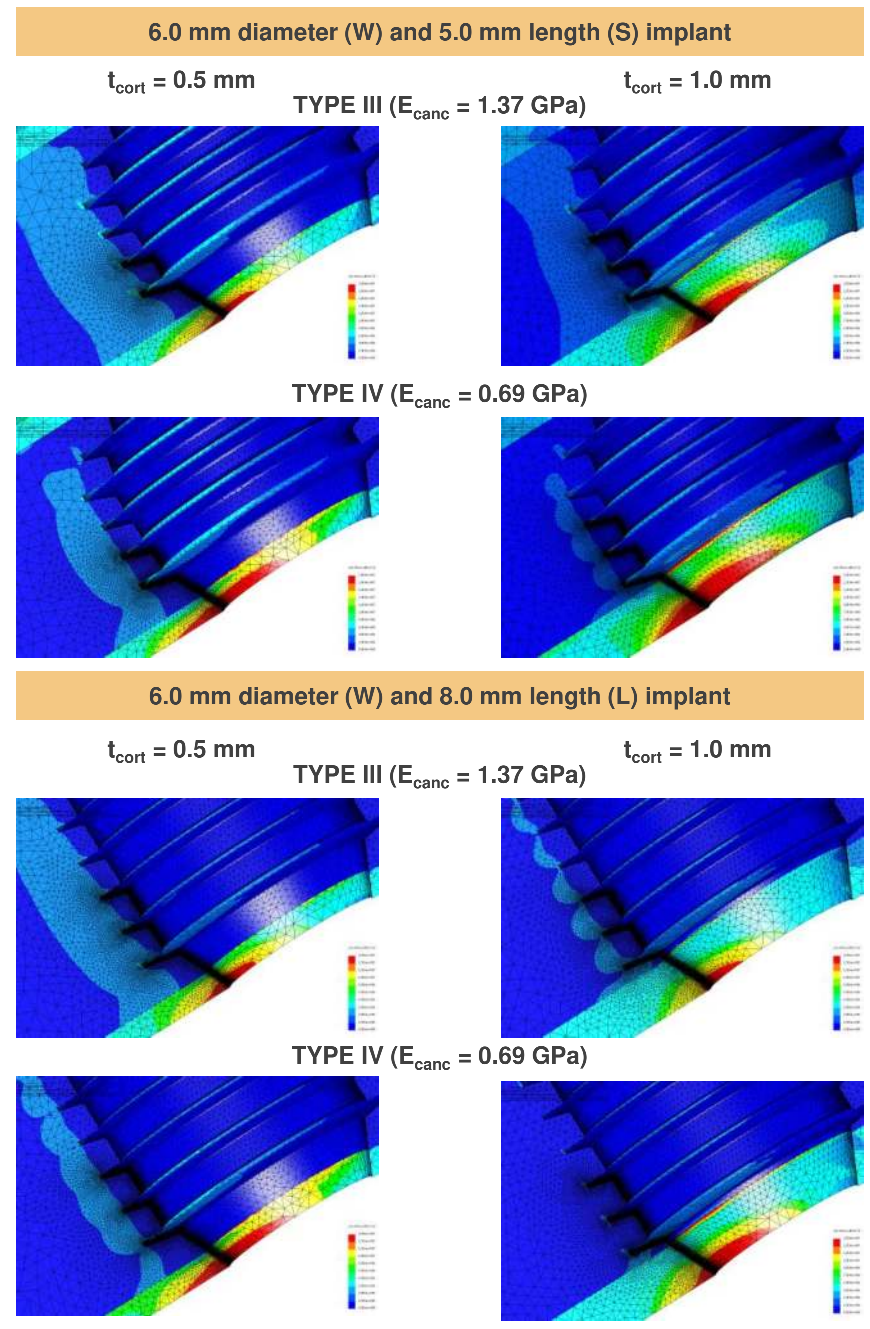


Fig. 3. Typical von Mises stress distribution along the critical bone-implant interface for selected implants and bone segments.

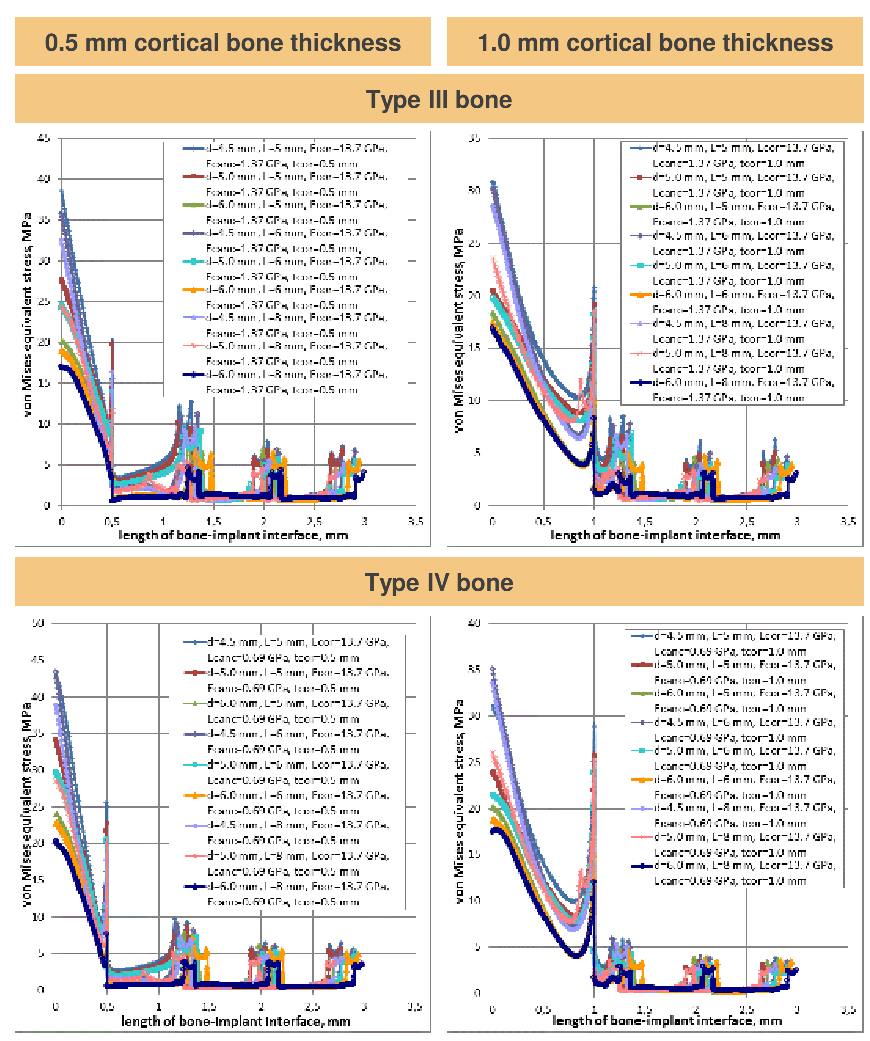


Fig. 4. Dependence of von Mises equivalent stress on the length of bone-implant interface in the neck area for the spectrum of implants placed into bone segment with 0.5 mm and 1.0 mm cortical bone thickness for types III and IV bone.

Conclusion

Studied Bicon Integra-CP™ implants have not caused 100 MPa ultimate stresses in crestal bone under mean, and even 275 N maximum experimental load. Bone stresses were influenced by cortical bone thickness and mainly implant diameter, contrarily implant length increase only slightly influenced the MES reduction. We believe this study supports clinical success of plateau implants in posterior maxilla due to their low susceptibility to poor bone quality and implant length. The outcomes of this study enhance understanding of the stress characteristics in the maxilla surrounding different-sized short plateau implants and provide a rationale for selection of appropriate implant for posterior maxilla.

References

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